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Generating shear waves in the human brain for ultrasound elastography: a new approach

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Abstract

One of the challenges of brain elastography is the generation of the shear waves inside the brain. The generation system has to bypass the body's natural protection while keeping a good level of comfort for the patient. We propose a shear wave inducing system for brain ultrasound elastography. In this paper we will validate this system *in vitro* on a tissue mimicking phantom by doing shear wave velocity measurements. The system proves to work well on phantoms and to be comfortable for the patient. Further work will include measurements *in vivo*.

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Keywords: elastography, brain, shear waves

1. Introduction

Brain elastography has been recognized as a being a promising diagnostic tool. The evolution of neurodegenerative diseases like Alzheimer's disease, Parkinson's disease as well as normal aging could be precisely evaluated using quantitative elastography (Sack et al. (2013)).

For ultrasound elastography, one of the challenges to overcome is the generation of the shear wave in the brain. Several methods have been developed for magnetic resonance elastography (Yeung et al. (2012); Sack et al. (2008); Kruse et al. (2008)): vibrating plate under the patient's head, bite-bar placed in the patient's mouth connected to a mechanical actuator. We found those methods to be unsatisfactory based on the lack of patient's comfort.

We propose here a new design to generate transient shear waves, based on a an apparatus developed for magnetic resonance elastography (Maitre and Darrasse (2012)).

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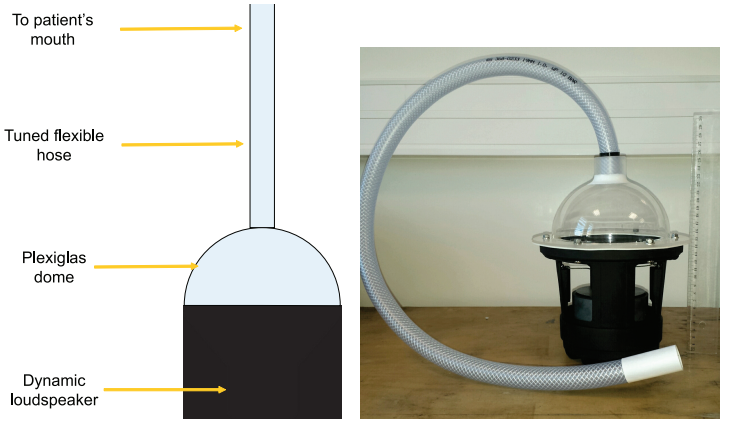
2. Apparatus design

2.1. General design

The apparatus is composed of a low frequency loudspeaker (Monacor RAPTOR-6-4), affixed with a tuned flexible hose. A Plexiglas dome is used to connect both parts hermetically. The end of the tube is placed in the patient's mouth.

The signal generation is done with a standard function generator connected to an audio power amplifier (Crown XlLi 1500). This setup allows us to generate signals in the loudspeaker bandwidth: 3-800 Hz. The design can be seen in figure 1.



(a) Design schematic (b) Actual design

Fig. 1: Representation of the apparatus

2.2. Frequency response

To study the frequency response of the system we used a sensitive microphone (Bruel & Kjaer 4188) placed at the end of the tube. The function generator was used to emit a standard frequency sweep from 10 Hz to 1000 Hz. The frequency response was measured for the system alone by placing the microphone in front of the loudspeaker, and for the full system by placing the microphone at the end of the flexible tube. Results are presented in figure 2.

We can observe the response of the loudspeaker alone, which match the manufacturer's specifications. The addition of the flexible tube brings about standing waves modes of frequency f_k, dependent of the length of the tube L and the speed of sound c given by the following relation:

$$f_k = \frac{(2k+1)\,c}{4L} \tag{1}$$

In this example, we tuned the tube to get a maximum response in the bandwidth 50-200 Hz. This bandwidth is a good compromise between a wavelength short enough to get good quality measurements in the brain (λ in the centimeter range) and attenuation.

3. *In vitro* validation

The validation is done in in vitro conditions, using a tissue mimicking phantom made of a mixture of a triblock copolymer SEBS (Kraton Polymers, Univar, France), dissolved in white mineral oil (Nicolas et al. (2013)). The scatterers used were silica powder.. Those types of phantoms present multiple advantages over more classical ones

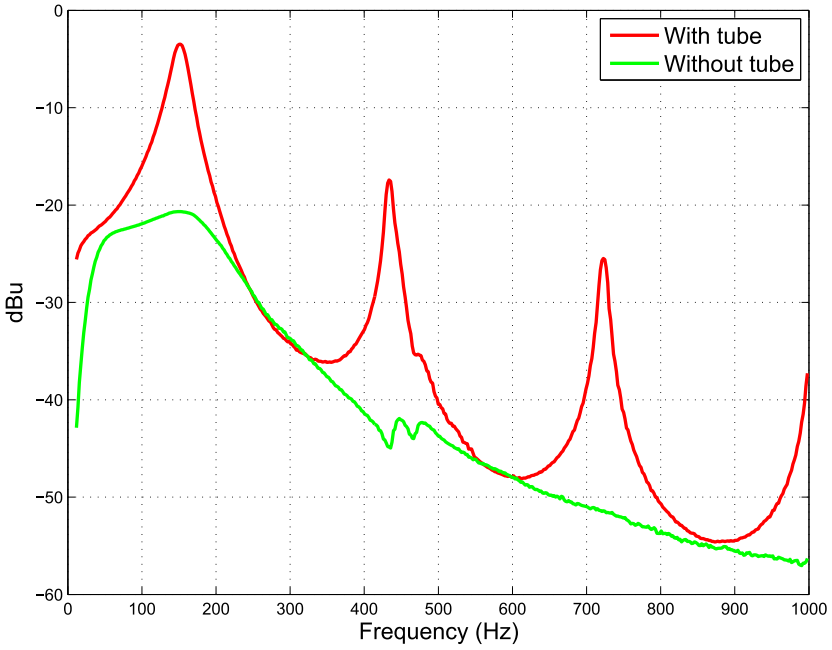


Fig. 2: Frequency response of the system with and without the flexible tube.

(agar gelatin), in particular excellent mechanical resistance and stability of the mechanical parameters (tested over 18 months). This particular phantom was made to mimic human brain tissue

Acquisition is done using an ultrafast ultrasound recorder (SSI Aixplorer) and a 2,8 MHz, 128 elements linear probe. Acquisition is done at 5 kHz.

The excitation signal is a transient sinusoid at 80 Hz.

Data obtained from the scanner is raw demodulated in-phase and quadrature components (complex IQ data). Using a subsample Doppler mean frequency estimation (Hoeks et al. (1994)), we can then compute the tissue velocity:

$$V(x,z,t) = \frac{\lambda}{4\pi T} \times \arg\left(\sum_{a=0}^{N_a} \sum_{b=0}^{N_b} IQ(x, z-a, t-b)\, IQ^*(x, z-a, t-b-1) \right) \tag{2}$$

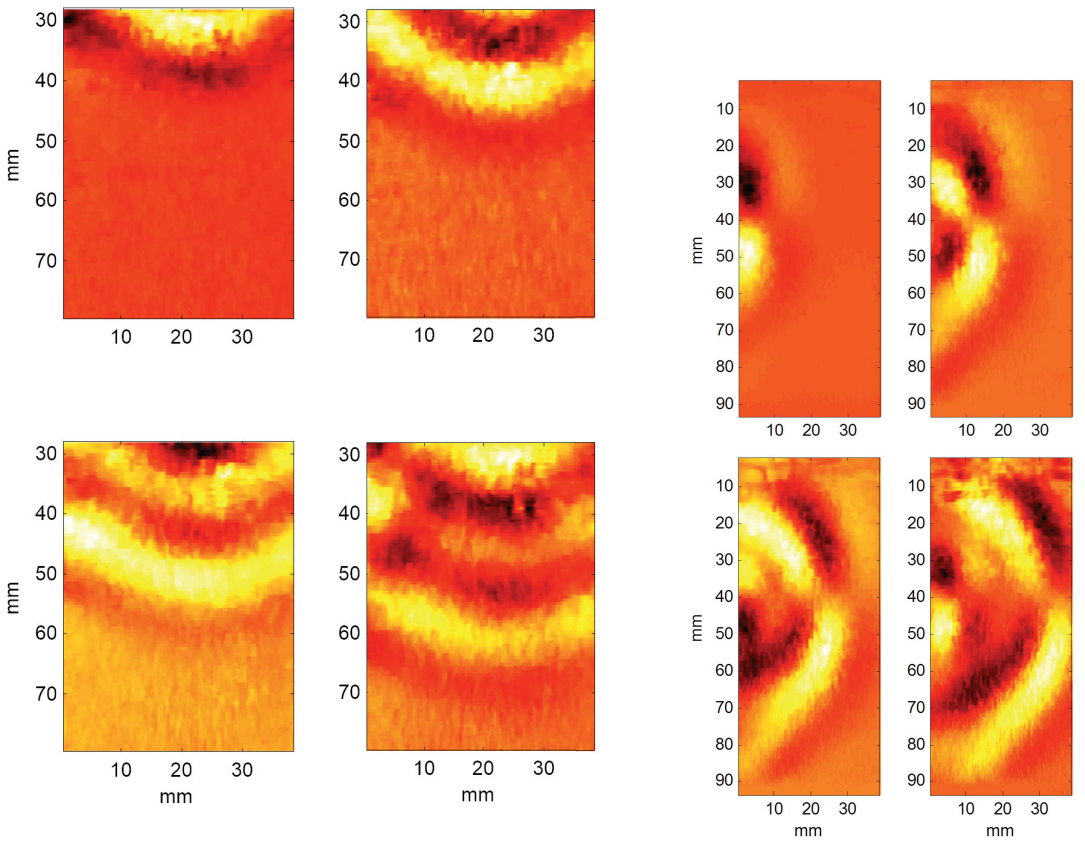
The axial resolution obtained is $1\lambda = 0.5$ mm. For each subsample volume at a given depth, the tissue velocity is estimated with an observation window of 8 samples with 50% overlap, giving us a temporal resolution of 0.4 ms.

An example of transverse tissue velocity fields computed with the method is shown in figure 3. We observe a typical radiation pattern for a piston.

From the transverse velocity fields, we can compute the shear wave velocity, assuming the shear wave propagates in one direction The calculations are done in the frequency space, using the complex spectral amplitude of the transverse velocity. The maximum of the spatial Fourier transform of this amplitude gives us k, the wave number for each frequency. We can then deduce the transverse wave velocity c_T, with $c_T(\omega) = \frac{\omega}{2\pi k(\omega)}$.

The excitation signal used allows us to compute velocity and attenuation within a good confidence interval in the band 65-95 Hz. By repeating the measurement (3 distinct measurements with 20 computations each time across different depths), we get a the IQR shown in figure 4.

Velocity computed with good precision (0,02 m.s-1), with a measurable dispersion ($2,5.10^{-3}$ m.s^{-1}.Hz^{-1}). Those measurements are in accordance with previous testing done on the same phantom (Nicolas et al. (2013)).



(a) First direction (b) Second direction

Fig. 3: Tissue transverse velocity fields along 2 directions. 9 ms between each frame

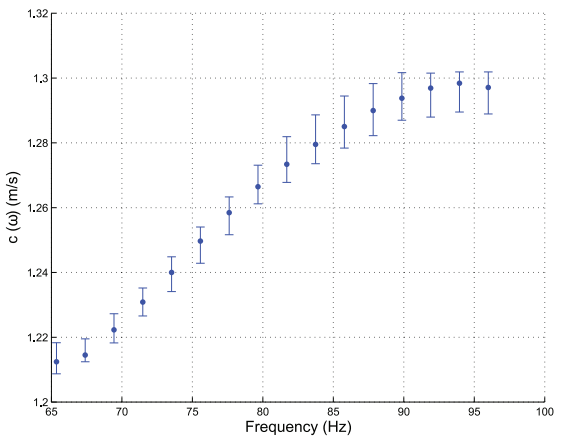


Fig. 4: Shear wave velocity measured in tissue mimicking phantom.

4. Conclusion

The apparatus presented here is a good alternative to existing mechanical generators. The flexibility of the system allow us to use a variety of excitation signals. In vitro testing has proven that the shear wave produced can be tracked and its characteristics measured. Initial testing *in vivo* has proven to bring a good level of comfort to the subjects. Work is being done to measure precisely shear wave speed inside the brain using transient excitation.

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